M.O. 548 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 80, No. 944, FEBRUARY 1951

Mr. C. J. P. CAVE, M.A., J.P.

Captain Cave, as he came to be respectfully and affectionately known by the officers and men of the Meteorological Section of the Royal Engineers, was a pioneer in the investigation of the upper air, an acute observer of meteorological phenomena, and an expert photographer of clouds. Cave was born in 1871 and educated at the famous Oratory School, Edgbaston, and Trinity College, Cambridge. He was elected in 1899 a Fellow of the Royal Meteorological Society, of which he was President in 1913–14 and, a second time, in 1924–25. He died on December 8, 1950 after a short illness.

Cave's outstanding meteorological work began in 1903. Two years earlier a Committee of the British Association, with W. N. Shaw as chairman and W. H. Dines as secretary, had been formed in co-operation with the Royal Meteorological Society to initiate the investigation of the upper atmosphere by means of kites. Shaw in a letter to *The Times* invited the co-operation of volunteer observers—in places where piano wire, miles of which were used in flying the kites, would not cause too much trouble if the kite broke away and trailed the wire across the country. Cave responded, installed his own gear at Ditcham Park, Petersfield, and so began his upper air work which was to extend over many years. The kites and the meteorographs recording pressure, temperature and humidity were designed by W. H. Dines; and so meteorologists in England began to learn actual facts about the lower troposphere. But what about higher levels ? Cave obtained some de Quervain theodolites, set out a base $1\frac{3}{4}$ miles long and began his fine series of pilot-balloon observations. On January 25, 1907, he sent up the first of the "registering" balloons, carrying the new 1 oz. instrument (2 oz. with its sun-shield) designed and made by W. H. Dines, the records from which provided all our knowledge of the temperature of the high troposphere and stratosphere over the British Isles until the introduction of the radio-sonde 25 years later.

From his observations of upper wind Cave was the first to demonstrate in 1908 the rapid decrease of wind in the stratosphere—in agreement with the theoretical deduction from the fact that in the stratosphere the lowest temperatures occur over the anticyclones, the reverse of conditions in the troposphere. In his Presidential address in 1914 he generously acknowledged the assistance he had received from meteorologists in other countries—to quote his own words, "I can personally testify how English and American, French and German, Russian and Scandinavian are all ready to help each other. There is

no jealousy in the upper air; international barriers are broken down." Three years earlier he had hospitably entertained, at Ditcham Park, British and foreign meteorologists and allied scientists attending the meeting of the British Association at Portsmouth (notable for the discussions on the new subject, relativity, opened by E. Cunningham, and on stellar distribution and movement, the " bun " universe, opened by A. S. Eddington). Eleven years later after expressing his regret at the lack of endowment of meteorological science in this country he reminded his audience: " There is no dearth of problems to be solved. Recent advances have left us like Cortez on a peak in Darien, and all the Pacific lies before us to explore."

In addition to his observations at Ditcham Park, Cave made observations with pilot balloons in Barbados. His book, published in 1912, " The structure of the atmosphere in clear weather " was based largely on the results of his own observations, and was illustrated with photographs of models depicting the wind at different levels on occasions of different character of variation with height. In 1926 he published a charming little book " Clouds and other weather phenomena for artists and lovers of nature " which included a number of his own beautiful photographs of clouds. A new edition of this book was issued in 1943.

When meteorologists were first commissioned for service with the army in France in 1915, Cave offered his services and was commissioned as captain. He came to St. Omer, and undertook the instruction of observers transferred mainly from the Artists Rifles and without previous meteorological training of any kind, and their posting at suitable places behind the front. When he had finished this, he returned to England and gave a fuller training at Old Sarum to the recruits needed for France and other theatres of operation. Many of those he trained, among them Sir Robert Watson-Watt, regarded him as their father in meteorology and look back with pleasure to the days when he was initiating them into its truths and its beauties. We, in France, on relatively mediocre commons, received at Christmas 1915 a reminder of his thoughtfulness in the shape of a parcel of delicacies from a notable Piccadilly firm.

Phenology was another aspect of meteorology in which Cave was interested, and he took part in the preparation of the *Phenological Report* of the Royal Meteorological Society from 1926 to 1934.

In the last decades of his life Cave devoted much of his time to archaeology, and, in particular, applied his photographic skill to photograph the roof bosses, often nearly hidden and practically inaccessible, in mediaeval cathedrals and churches. In this he was most successful and his book, published in 1948, was universally acclaimed as an outstanding contribution.

Cave, who had presided at the celebrations of the 75th anniversary of the Royal Meteorological Society, was fortunately able to be present at the centenary meeting and dinner in April 1950, to the great delight of all who knew him. Modesty, courtesy and generosity were his outstanding gifts. Many present and past members of the staff of the Meteorological Office were able by their presence at the memorial service at Brompton Oratory on December 15, to pay a last tribute to a great gentleman and fellow worker in meteorological science and art.

E. GOLD

I am glad to have this opportunity of paying tribute to the memory of Mr. C. J. P. Cave. Although I first knew him on Salisbury Plain in 1918 when he was in charge of the Meteorological Section (Home) of the Royal Engineers, to which I then belonged, it was in 1922 that he appointed me as his scientific assistant. He was interested in a number of meteorological problems and wanted some help in pursuing them at his home at Stoner Hill, Petersfield. Foremost amongst the routine work which he instituted was the observation of atmospherics on a rotating frame aerial by a method which had recently been developed by Mr. (now Sir Robert) Watson-Watt. In the grounds of Stoner Hill, to which he had moved from Ditcham Park a year or two earlier, Mr. Cave had established a meteorological station including Stevenson screen, rain-gauge and rain recorder, Dines anemometer and an evaporation tank; and daily observations were maintained and autographic records tabulated. My keenest recollections are of his daily morning visits to the room in a near-by cottage which served as my office where we would plan the day's work. The friendly warmth of his greeting and the kindly courtesy with which he directed and encouraged my labours were characteristic of his gracious personality. Often at the end of the day we would talk in his study of what we had achieved, and on these occasions he was liberal with stimulating comment and appreciation. I shall always be grateful that it was my privilege to begin my meteorological career under so wise and sympathetic a guide and counsellor.

S. P. PETERS

ESSAY ON FRONTOGENESIS AND FRONTOLYSIS

By H. H. LAMB, M.A.

This essay was mainly written during a relatively slack period at an aviation station some time after the war. Although it is not a research paper, it has been put forward as a useful practical summary which brings together a number of points of general interest.

Part I

Introductory.—The theoretical treatment of frontogenesis and fror.tolysis due to Bergeron[1] and Petterssen[2] has not led to such systematic use in the technique of weather analysis and forecasting as the importance of the subject might suggest. Regions of confluence leading to increasing thermal gradient are, however, watched for on thickness charts, where these are in use, and their significance in relation to the occurrence of jet streams in the upper troposphere and for future developments down-wind in the developing jet is increasingly appreciated; but fronts are often entered on the charts for quite other reasons.

Frontolysis has been largely passed over in the meteorological literature as a mere counterpart of frontogenesis. Fronts often disappear from the charts for no clearly understood or expressed reason, or only because they have moved into regions with which the forecaster is little concerned.

The object of this essay is therefore to give a little further consideration to these problems and bring them into some perspective. We need not concern ourselves with precise criteria for the existence of a front, since we propose

rather to discuss practical illustrations of the processes of formation and decay and their implications in the case of fronts which are generally accepted. The exact nature and the complex, finer structure of fronts are still a matter for investigation and research. Meanwhile we may use Douglas's definition of a front as " essentially a line of discontinuity in the horizontal distribution of temperature, with an associated discontinuity of pressure and wind".

The final criterion for entry or omission of a front from the map seems likely to remain somewhat arbitrary and dependent upon considerations of usefulness, but it needs emphasizing that when simplification of a complex map is desired this may sometimes be permissibly achieved by omission of weak systems (and weak portions of formerly continuous frontal systems) but never by distortion to achieve artificial conformity with a text-book model. Attention given to actual frontal shapes, arising with various flow patterns and distributions of velocity, proves very helpful in interpreting isolated or vestigial weather phenomena.

Petterssen, distinguishing between the four possible types of fluid motion—translation, rotation, divergence or convergence (on a point), and a deformation —uses the picture of the typical deformation field reproduced in Fig. 1, and defines frontogenesis and frontolysis in terms of it[3]: " We consider a scalar quantiy S which has a continuous distribution in the horizontal plane (x, y). S may be represented by its equiscalar curves on a map. When time t varies the S-curve (e.g. isotherms) will, in general, move relative to the co-ordinates of the chart. We then say that *we have frontogenesis if the S-curves move in such a way that they tend to create a discontinuity along a line in the field.*" The reverse case is frontolysis.

The diagram is properly applied to stream-lines, but if considered in terms of hypothetical isobaric flow the important additional frontogenetic or frontolytic influence of ageostrophic motions must be allowed for.

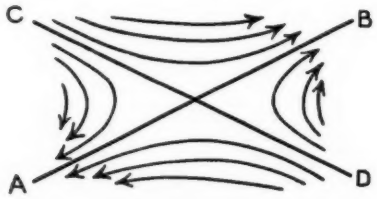


FIG. 1—DEFORMATION FIELD
(Stream-lines)

AB and CD (Fig. 1) are the axes of inflow and outflow respectively in a normal col circulation. Isotherms ranged parallel with AB in an initially weak thermal gradient will be brought progressively closer to one another along the line of the inflow axis AB, which therefore becomes a line of frontogenesis if this circulation persists. In the end widely different air samples from far distant sources at C and D will be brought towards one another near the line AB. Convergent (ageostrophic) motion is, however, needed to produce an actual discontinuity within the narrowing frontal zone; and the associated development of upgliding and undercutting will ultimately be spontaneous.

Isotherms initially parallel to CD would of course be drawn apart towards A and B, from which we see that CD is a frontolytic line.

Temperature fields in which the isotherms have various other orientations are progressively swung into alignment with AB or CD according as the initial angle between isotherms and inflow axis is less or greater than a critical value, which itself depends on the angle between the axes of the col; the effect of the col is accordingly either frontogenetic or frontolytic.

A significant outcome of the deformation process is seen when a really strong thermal gradient can be produced along the axis AB between, say, a cold source at C and a warm source at D (northern hemisphere). A strong thermal wind then develops in the same direction as the surface winds in the right-hand branch of the confluence, towards B. In this region jet streams are generated in the upper troposphere, though the strongest development of the jet may culminate some 1,000–2,000 miles down-wind as the surface wind strengthens in association with travelling cyclonic circulations which develop from waves on the sharpened surface front.

Nevertheless frontogenetic cols can seldom stay long enough in one place to produce a fully fledged front where none was before. Their main importance for the surface frontal pattern is in sharpening already existing weak fronts, old occlusions and frontal belts containing more than one former frontal system until they are once more strong, simple fronts capable of major activity.

For the actual birth of the more numerous fronts shown on our charts we must probably call in an altogether different process, such as that put forward by Refsdal[4] or that represented by Sawyer's occlusion breakaway depressions (see later).

We must also notice that the normal horizontal distribution of wind velocities in a depression, with light winds near the periphery, twists the frontal system forward near the centre and back near the edge of the storm in such a way that the trailing front approaches the inflow axis of the adjacent col. This means that the frontolytic case seldom arises in practice. Frontolysis must commonly be explained in other terms.

Frontogenesis.—The frontogenetic col is most effective if the axis of inflow lies in a geographical belt where a steep gradient of temperature of the earth's surface induces a corresponding zone of quick transition in the overlying air.

The most important geographical belts favouring frontogenesis* are:—

(*a*) In the North Atlantic Ocean off the east coasts of North America and Greenland, near the boundary of the Polar Ice Labrador Current and Gulf Stream waters. The cold surface west of the boundary is far more extensive in winter, when the American continent is cold, than in summer.

(*b*) The corresponding belt in the North Pacific Ocean off the coast of Asia to the Aleutians, to which similar remarks apply.

(*c*) From late summer through autumn the thermal gradient, around the fringe of the permanent ice in the Polar Basin along the north coast of Asia and North America, rivals (*a*) and (*b*) in importance.

*The basis of these ideas will be found in Bergeron's "Richtlinien einer dynamischen Klimatologie"[5].

(*d*) In late autumn through winter, as the continents cool down particularly in their eastern portions, (*c*) tends to be replaced by two belts dipping south-eastwards into the heart of the great continents:

(i) through Alberta along the flank of the northern Rockies, where mild air from the Pacific Coast meets the snow-covered interior of the continent;

(ii) a rather less definite north-west to south-east line near the White Sea and north Urals where mild air from the Atlantic and land-locked seas of Europe reaches the main continental interior with its winter snow cover. This line of thermal contrast is more fitfully maintained than (i), being itself considerably dependent on the patterns of air circulation prevailing. Occasionally advection around the Asiatic anticyclone carries warm air east along the north coast and restores belt (*c*) even in the depth of winter.

(*e*) In spring and autumn transitional periods (i) the Baltic Sea and (ii) the St. Lawrence Valley mark important zones of contrast between cold largely snow-covered regions to the north and warmer lands to the south; (ii) has also some importance at other seasons.

(*f*) In winter and early spring a belt of strong thermal gradient runs from the coast of north-west Africa through the Mediterranean across Turkey and the Persian highlands finally becoming weaker and more variable in position towards Mongolia and Tibet. The corresponding feature of deep winter in the western hemisphere is a prolongation of belt (*a*) into the Gulf of Mexico.

(*g*) In the southern hemisphere the main belt is that which surrounds the Antarctic continent and, in winter, the edge of the pack-ice.

(*h*) Subsidiary frontogenetic zones occur near the coasts of the warmer southern continents at suitable seasons of the year.

The most favourable circumstances of all for frontogenesis occur when an already existing air-mass boundary (or old frontal system) moves into one of these geographical belts and happens to come under the influence of a suitably orientated frontogenetic col there (see also Rodewald[6]).

Climatological charts show that belt (*a*) in the western Atlantic corresponds roughly to the inflow axis of the col in the mean winter pressure distribution between the Azores–Bermuda high and the north Canadian anticyclone and between the Iceland low and low pressure in the Mexican Gulf. This means that the frontogenetic pattern repeatedly occurs when cold, continental winter anticyclones move south-east towards the Atlantic seaboard of North America behind the occluded fronts of depressions which have passed out on to the Atlantic. These old occluded fronts are then sharpened and transformed by the frontogenetic deformation field into the so-called Atlantic polar front, on which new depression families arise.

Similar sequences take place off the east coast of Asia and less regularly in other parts of the world.

It is interesting to watch what happens when a frontogenetic col appears in a single air mass over one of these geographical transition belts favourable to frontogenesis. Embryonic frontal phenomena begin to appear. Sheets of thin altostratus or altocumulus start to form as the convergence in the horizontal wind field forces upgliding at any minor surfaces of discontinuity, even former subsidence surfaces, existing aloft. Stratus sheets may be similarly formed in the

lower levels. Slight rain or drizzle sometimes results. All this may happen before the surface temperatures and humidities have developed any sharp discontinuity. And then, in most cases, the movement of distant pressure systems causes the col to shift; the pattern of flow ceases to be favourable for front formation, and the frontal phenomena, that have been appearing, dissipate without having come to anything. Even in the most likely geographical regions the frontogenetic circulation pattern must persist for many hours if a front is to be formed. The length of time required is a variable quantity depending on wind components along the axis of inflow in the opposing air streams as well as on the physical properties of the air involved.

It is clear that not many fronts would be formed in the atmosphere if the process described by the theoretical deformation-field diagram (Fig. 1) were the only one capable of creating a front. Too great a coincidence of favourable circumstances is required.

The number of fronts shown on the daily weather maps of every forecasting office compels us to consider what alternative processes may lead to front formation.

The most prolific process giving new discontinuity lines in the horizontal field of flow is believed to be that represented by the following sequence: bent-back occlusion and re-occlusion of pseudo warm sector, followed by the same process again, often repeated several times in one depression. This sequence, illustrated by the diagrams in Fig. 2, due to Refsdal[4], is a fertile source of secondary cold fronts. The successive bent-back occlusions may be treated as secondary cold fronts at quite an early stage in their history. Occlusions, across which the temperature contrast is in the reverse sense, tend to die away for obvious reasons when bent back around the rear of the depression. Later association with a frontogenetic col will be liable to convert any secondary front into a front of major importance.

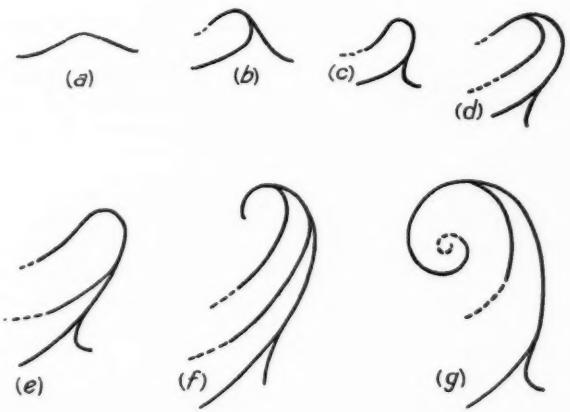


FIG. 2—DEVELOPING FRONTAL PATTERN IN A MAJOR DEPRESSION
(after Refsdal)

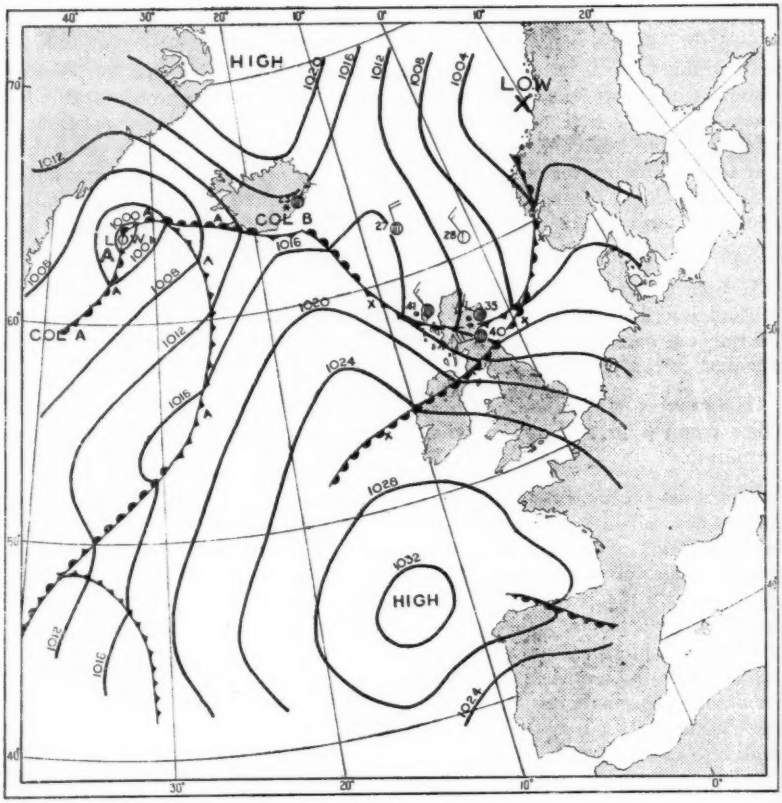


FIG. 3—SYNOPTIC CHART, 0600 G.M.T., FEBRUARY 22, 1946

Conventional analysis tends to pick upon the major fronts and ignore the minor discontinuities produced by this process. Difficulties arise with some old depressions in which all the fronts are rather minor, and all have a more or less equal claim to recognition.

A case of this kind arose on February 22–25, 1946, (Figs. 3–6). Space forbids the entry of more than a few illustrative observations at points of interest, insufficient for actual proof. Conventional analysis confined to a single warm front, cold front and occlusion entirely failed to explain the patterns of wind and weather in the depression A as it developed and moved across the British Isles. Considerable areas experienced continued warm-sector-like conditions after one or two wind veers and rising pressure had set in. The depression might reasonably have been treated as more or less non-frontal, with intermittent rain and drizzle and local clearances over its entire area. Individual stations where detail was important might nevertheless trace three or four successive weak fronts passing and bringing a final clearance only when the veering wind at last reached a point giving some orographic shelter.

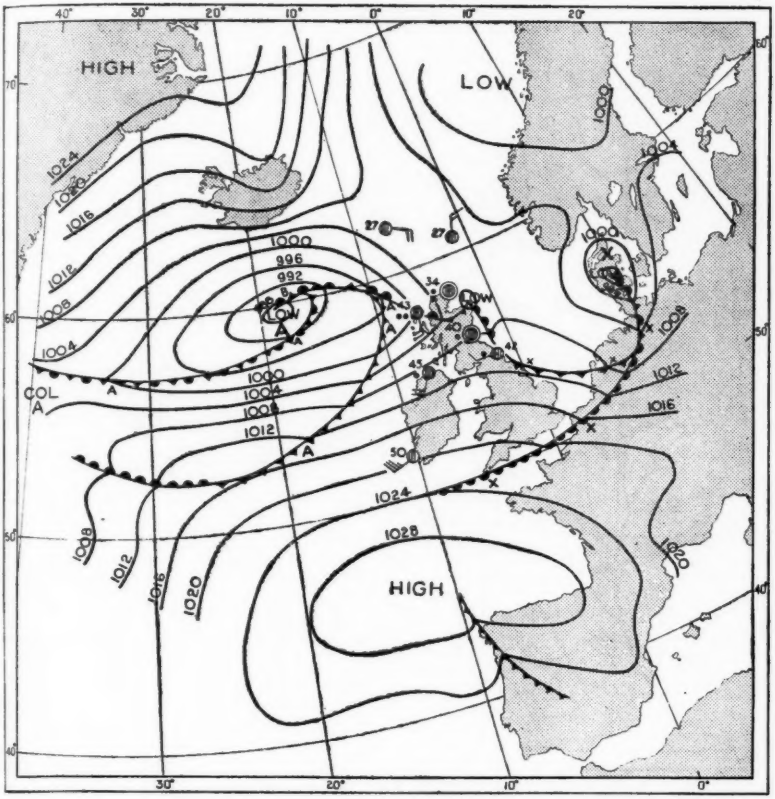


FIG. 4—SYNOPTIC CHART, 1800 G.M.T., FEBRUARY 22, 1946

Low A is seen, already partly occluded and with a depth of 1000 mb., west of Iceland on the morning of the 22nd (Fig. 3). In the following 24 hours the centre moved quickly east-south-east into the North Sea, the original occlusion A became secondary cold front B on the map for the 23rd (Fig. 5), and in the course of re-occlusion the centre deepened to 980 mb., producing a long new frontal line, occlusion B, which already showed signs of repeating the process. The centre deepened further to 968 mb. when it approached Denmark on the evening of the 23rd and as the second pseudo warm sector occluded. Ultimately occlusion X of the former Scandinavian low was swept around the rear of low A as a further secondary cold front over Denmark when the deep centre moved into the Baltic. With this final development completed, the centre began to fill up, and, by the evening of the 25th, it was represented only by several shallow centres of 1008 mb. along a single occlusion coiled up over the Baltic States, south Sweden and central Russia (see Fig. 6).

Figs. 3 and 4 further show how occlusion A was not only bent back but necessarily rotated into alignment with the inflow axis of col A over the Atlantic

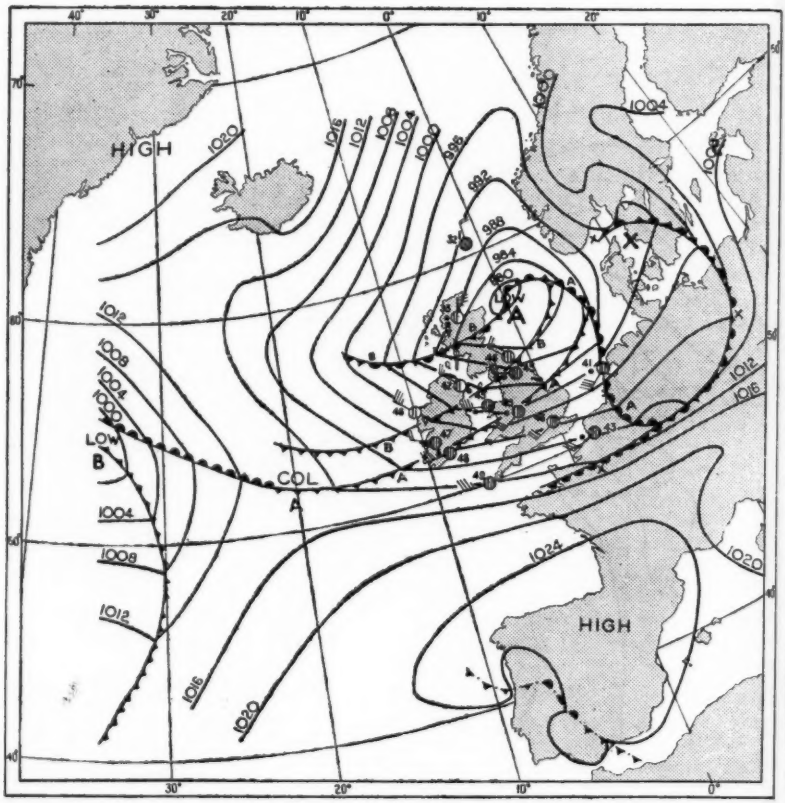


FIG. 5—SYNOPTIC CHART, 0600 G.M.T., FEBRUARY 23, 1946

south-east of Greenland and thereby came under the influence of the frontogenetic effect of the deformation field, which seems to have prolonged the front to the westward as time went on. Fig. 5 shows the primary cold front A likewise brought into line with the frontogenetic axis of the col as a natural consequence of the circulation pattern. We see too how a normal development of the circulation is quite unlikely to produce a frontolytic orientation of the front in the col.

Fig. 6, marking the end of the sequence, is an interesting example of the fertility of the occlusion process at different points along the subtropical-subpolar air-mass boundary in producing a welter of new, offshoot fronts, any one of which may later be subjected to the sharpening process of a frontogenetic deformation field. The occlusion marked A on this map is already the product of closing together (consolidation) of a bunch of occlusions (A, B and X) developed in the earlier stages of the life history of depression A. Consolidations of this kind are frequent, but complete amalgamation of the successive fronts requires ageostrophic motion and is not always achieved. Cold front C was

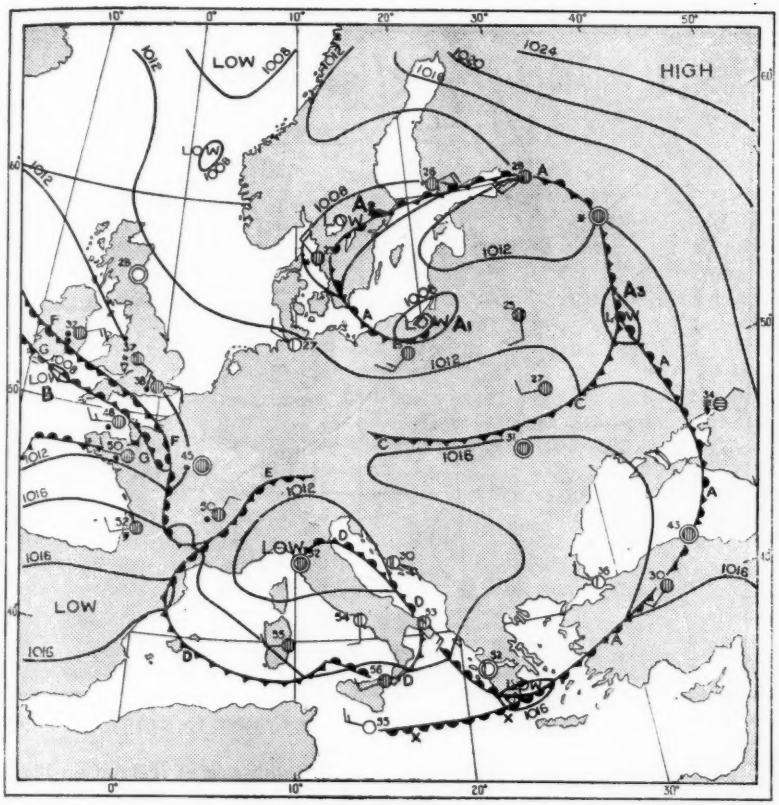


FIG. 6—SYNOPTIC CHART, 1800 G.M.T., FEBRUARY 25, 1946

formerly an extraneous system drawn into the circulation of the rear side of low A from Scandinavia and now helps the development of a new depression over Russia with a warm sector formed between the old warm occlusion A and the cold front C; this system moved south-east towards the Caspian Sea with renewed intensity of precipitation. Occlusions D, E, F and G are new derivatives of the activity along the same parent front, and the occlusions F and G are in process of being closed together into a single, sharp front by the pattern of winds over northern France and southern England. Ageostrophic components are evident. The subsequent activity on the sharpened front between the mild Atlantic air masses to the south and the Arctic air mass with freezing temperatures to the north of the confluence gave one of the heaviest snowfalls in recent years in Kent.

The spotting of this situation, which will squeeze together parallel fronts (simplifying the map) or sharpen and energize the frontal belt, is an important use of the deformation-field pattern (Fig. 1). The building up of potential energy and quickening of upgliding motions with increased rainfall commonly take 24–48 hours to mature.

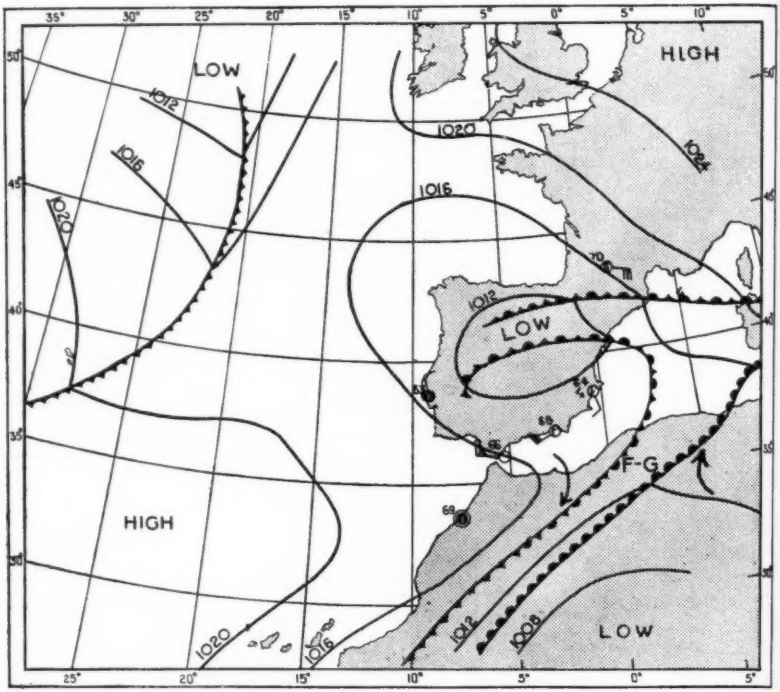


FIG. 7—SYNOPTIC CHART, 0000 G.M.T., JUNE 19, 1945

The warm-front wave disturbance forming south-east of Iceland on Fig. 3, rather as a break away running ahead of the depression A and travelling south-east to Scotland during the 22nd, may be looked upon as an example of this action in the case of the frontogenetic col B. The south-westerly air stream (tropical maritime air) which gave a temperature of 43°F. at Vestmannaeyjar, south Iceland, and the arctic air stream with temperatures around 23°F. met from directly opposite directions at this section of the front. The warm-front wave, which appeared, travelled quickly south-east in the strong thermal gradient, bringing rain and sleet far ahead of the main depression.

Break-away depressions forming at the point of occlusion and running ahead of the parent low, studied by Sawyer[7], commonly produce one long new frontal line upon our maps by prolonging the occlusion. This process is therefore another source of new fronts.

Another interesting frontogenetic sequence occurred over north-west Africa and the regions to the north on June 19, 1945.

The chart for 0000 on the 19th (Fig. 7) shows a rather complex situation with parallel fronts over north Africa associated with the very old depression over Spain. Pressure gradients are weak but a frontogenetic col is marked on the chart near Algiers, and the temperature contrasts between the air masses

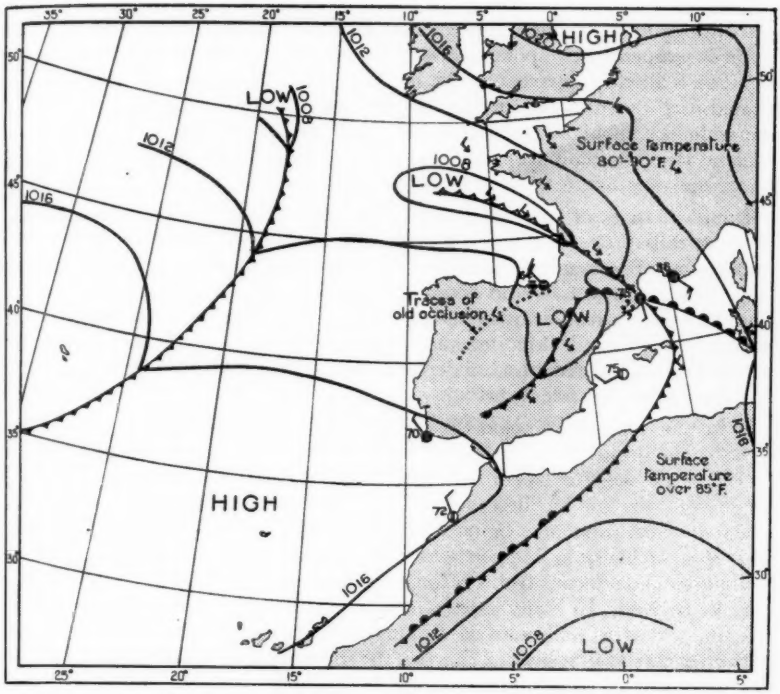


FIG. 8—SYNOPTIC CHART, 1200 G.M.T., JUNE 19, 1945

approaching one another at this point are great. By 1200 on the same day (Fig. 8) the situation in the frontogenetic belt has been reduced to a single sharp front. The resulting simple warm sector over the western Mediterranean continues northwards aloft as a broad expanse of altocumulus castellatus clouds over France; and its trough-line, the upper cold front over the Bay of Biscay, is producing a sharp trough in the isobars over the Bay. Aircraft reports indicated conditions in the lifted air mass getting progressively more stable westwards to tail out as a thin sheet of altocumulus, or high stratocumulus, about the 8,000-ft. level in 9°W. over the Bay. B.O.A.C. and K.L.M. aircraft flying along the Atlas mountains *en route* from Malta to Rabat reported severe thunderstorms in frontal medium cloud in the region where the sharpened front is shown, whilst the general increase in activity of the depression system is demonstrated by the much greater number of reports of lightning and atmospherics shown at 1200 G.M.T. on the 19th, than at the previous midnight (compare Figs. 7 and 8). Recent thunderstorms were reported on both charts but none at the hour of obsevation at the stations used. The transformation of the frontal pattern went one stage further during the afternoon and evening of the 19th. The westerly breezes developing behind the pressure trough associated with the upper cold front over the Bay of Biscay brought in cool Atlantic air to south-west France. The trough now corresponded to the main temperature contrast on the surface map between the cool oceanic air (polar

maritime) and the strongly heated European and African air masses with high surface temperatures (polar continental and tropical continental). This situation is already apparent in Fig. 8. As a result the upper front quickly extended itself down to the surface as a normal cold front, which, together with the wide belt of high-level instability cloud and thunderstorms ahead of it, became the dominant feature of the map, leaving merely traces of the old occlusions over Spain as relics of little consequence.

Rapid changes of the isobar pattern, under the influence of considerable pressure falls probably associated with the release of instability aloft superimposed on a previously flat situation, made the stages of this quick development (Figs. 7–8) hard to follow in detail. Nevertheless this conversion of an upper front to a surface front is by no means unique. British meteorologists who have been stationed in the Mediterranean speak of a fair number of occasions on which fronts appeared to " build downwards " and some instances have been noted in higher latitudes.

A further type of frontogenesis to which Mr. Douglas has drawn attention is liable to occur in southerly or south-westerly sweeps of returning polar maritime air over the North Atlantic. When the southernmost extremity of a tongue of polar air has become very shallow and considerably modified, the effective warm front may be transferred north to the limit of deeper cold air. This is most likely to happen where an old, weak front, such as one of the trailing secondary cold fronts of depression A (Figs. 3–6), already exists and may be revived. In many cases of this kind, however, vestiges of both fronts remain, unless a well marked frontogenetic convergence and deformation pattern occurs to simplify and sharpen the situation, or the geographical factors are particularly favourable.

REFERENCES

1. BERGERON, T.; Uber die dreidimensional verknüpfende Wetteranalyse. Teil 1. *Geofys. Publ., Oslo*, **5**, 1928, No. 6.
2. PETTERSSEN, S.; Contribution to the theory of frontogenesis. *Geofys. Publ., Oslo*, **11**, 1936, No. 6.
3. PETTERSSEN, S.; Weather analysis and forecasting. New York and London, 1940.
4. REFSDAL, A.; Zur Theorie der Zyklonen. *Met. Z., Braunschweig*, **47**, 1930, p. 294.
5. BERGERON, T.; Richtlinien einer dynamischen Klimatologie. *Met. Z., Braunschweig*, **47**, 1930, p. 246.
6. RODEWALD, M.; Das Dreimasseneck als zyklogenetischer Ort. *Met. Z., Braunschweig*, **54**, 1937, p. 469.
7. SAWYER, J. S.; Formation of secondary depressions in relation to the thickness pattern. *Met. Mag., London*, **79**, 1950, p. 1.

A SYSTEMATIC SMOOTHING TECHNIQUE USEFUL IN THE CONSTRUCTION OF MARINE CLIMATOLOGICAL CHARTS

By T. H. KIRK, B.Sc.

Current meteorological atlases for ocean areas include charts showing the spatial variation of monthly mean values of different climatic elements for each month of the year, the mean values being derived from ships' observations made over a long period of years. In preparing these charts it is usual to group the observations in each 2° square and to assume that the mean value applies to the centre point. In practice larger or smaller areas (e.g. 5° or 1° squares) may be

used depending on the number of observations available. A refinement of this procedure consists of grouping observations at their centroid instead of at the centre of the square.

Whatever variation is used the next task is to smooth the mean values depicted on each monthly chart. Current practice consists of smoothing spatially the values on each chart while taking care that no great inconsistency arises between successive charts. This is not easily achieved where observations are sparse, and, without some knowledge of the differences of seasonal change from place to place, it is indeed difficult to assess consistency. In the construction of "Monthly sea-surface temperatures of North Atlantic Ocean"* the following method was found useful in helping to distinguish between casual and significant detail. A series of derived charts was drawn in which the position of a particular isotherm was depicted for each month on the same chart. Detail which violated the steady progression of sea temperature throughout the year was smoothed. The application of this method calls for considerable caution, especially for those mean isopleths near maximum and minimum values. It is important not to alter the type of annual variation characteristic of any particular place. The limitations of this procedure are apparent, though its usefulness in practice is sufficient evidence that more attention should be paid to the time sequence.

It is possible to smooth the data systematically with respect to both space and time by applying the method of harmonic analysis to the raw data, i.e. to the calculated monthly mean values regarded as a time sequence. The following parameters are then obtained for each square:—

a_0, the annual mean,
a_1, the amplitude of the annual component,
a_2, the amplitude of the semi-annual component,
A_1, the phase of the annual component, and
A_2, the phase of the semi-annual component.

It is usually neither necessary nor justifiable to work with additional components. The climatic element, T, may then be expressed in the form:—

$$T = a_0 + a_1 \sin (t + A_1) + a_2 \sin (2t + A_2),$$

t (time) taking values at 30° intervals from 0° to 330°.

The parameters a_0, a_1, a_2, A_1, A_2 define the element T, and, once evaluated, replace the raw data. To ensure a spatial consistency, charts are constructed to show the distribution of each of the harmonic parameters, the isopleths being smoothed by eye or according to some arbitrary rule. These charts of smoothed values of the harmonic parameters afford all the information that is required of the element T and depict it in a highly condensed form. Using the charts it is simple to write down an analytical expression for T at any place.

Although this method of representation may meet the needs of the scientific worker it is not suitable for the mariner and those others who require a mean or average picture at successive intervals of time. Charts at monthly intervals are easily constructed by calculating T from the smoothed values, applying the formula:—

$$T = a_0 + a_1 \sin (t + A_1) + a_2 \sin (2t + A_2)$$

for as many positions as may be considered necessary.

*London, Meteorological Office, 1949.

At the suggestion of Mr. Durst this method has been applied to construct a chart of mean monthly sea-surface temperature of the North Atlantic Ocean for a specimen month (May). The satisfactory result obtained demonstrates that the technique will be useful in eliminating inconsistencies in the preparation of monthly mean charts of sea-surface temperature.

It is appreciated that the method has been employed in the most favourable conditions. Good mean values of sea-surface temperature can be obtained from relatively few observations and few areas have a density of observations comparable with that of the North Atlantic Ocean. The application to other climatic elements and to other regions depends on the density of the observations in both space and time. As more data become available the method should be useful at least for ensuring that a sequence of charts will show a reasonably true annual variation at every place.

EXPOSURE OF EARTH THERMOMETERS

By A. J. WHITEN

For some time past there have been doubts as to the suitability of steel tubes for the exposure of thermometers below the surface of the earth.

To determine whether there was any systematic error in the readings of thermometers so exposed, two pairs of sheathed, lagged thermometers have been installed at Cuddington, Surrey, at depths of 1 ft. and 4 ft. One pair are in ordinary steel tubes, while the others are suspended in brass cells, to which access is obtained through lengths of rubber tube, such as is used for radiator connexions in internal combustion engines.

The interior diameter of these tubes is somewhat greater than that of the steel tubes, being 2 in., so as to permit the thermometer to drop freely without binding on the sides. To check any tendency to convection in the tube, a " collar ", composed of two pieces of hose of smaller diameter, fitted telescopically, is held between rubber rings round the sheath of each thermometer (see photograph facing p. 64).

These instruments form part of an installation of ten thermometers and a themograph in an enclosed patch of grass 3 ft. square (see photograph facing p. iii of cover), so there is little question of differences on account of siting.

The thermometers, which were supplied by the Meteorological Office, are certified to have errors not greater than $\pm 0{\cdot}1°F$.

The first readings were taken on November 9, 1948, and temperatures have been recorded daily ever since, at 0900 G.M.T. At this hour all the instruments are in shade, the first sunlight falling on the steel tubes shortly after 0930 at midsummer.

During the two winters while this record has been kept, there has been little or no difference between the temperatures recorded by the two pairs of thermometers, but by the beginning of April each year, small but persistent differences became apparent, which increased to as much as $1{\cdot}5°F$. at times during spring and summer.

The greatest differences occurred at the end of each period of sharply rising temperature, the thermometers in the steel tubes always reading rather higher than those in rubber.

The greatest differences during 1949 were:—

June 14, 1·4°F.—This followed a spell of seven days with minima over 50°F., the maximum on the 13th being 79°F. with only 0·02in. of rain on the 13th. The previous five days showed some 30 hr. of sunshine, with less than 1 hr. on the previous day.

July 6, 7, and 8, with 1·5°, 1·4°, and 1·4°F. respectively.—This spell came after ten days with maxima mostly in the eighties and nineties, though during these three days 75°F. was the highest recorded in the screen. Minima had been between 47° and 61°F. There had been only 0·01 in. of rain and the five days' sunshine amounted to over 60 hr., though there was singularly little during the three days under review.

In 1950, up to the time of writing (mid July), most of the greatest differences were between June 7 and 14, when the average was 1·45°F. with a range between 1·2° and 1·7°F. During this time maxima ranged from 70° to 84°F., with minima mostly in the upper fifties, the previous few days having been somewhat cooler. There was 0·25 in. rain during these days, and on the 3rd there had been 0·83 in. During the preceding three days no sunshine was recorded, but there were 68 hr. during this week.

This was followed five days later by a difference of 1·6°F. on June 19, when maxima had been 71°F. or lower for three days and minima had been between 46° and 54°F. During the preceding five days there had been 1·5 in. rain and only 26 hr. sunshine.

With the heat of late summer in 1949 the differences diminished as the temperatures in the rubber tubes came closer to those in the steel. By the end of September these differences were only one or two tenths, and remained thus until the middle of October, when the steel tubes were showing slightly lower temperatures than the rubber. Throughout the autumn, differences were considerably less than during spring and early summer, only two instances of 1°F. being recorded, on November 22 and 25, which fell at the end of ten days during which maxima were high for the time of the year (upper forties and fifties), but grass minima sometimes approached frost. During these days there was little or no sunshine (10 hours) and 1·5 in. of rain. By December the differences had dwindled to insignificance, and did not reappear until April.

Throughout, as might be expected, differences at 4 ft. lagged some 2–3 days behind those at 1 ft., and were rather less than half their magnitude; but there was another point of some interest in the readings of the 4-ft. thermometers.

After the rubber tubes had been installed, with much hard labour involving digging a yard-square pit four feet deep in very heavy clay, it became apparent that the junction between the brass and the rubber was not completely watertight, and heavy rain found its way into this tube. There being no leak at the base of the brass cell, the water lay to a depth of some 10 in. at the bottom of the tube, and could only be removed by soaking it out with a piece of muslin on the end of a five-foot pole (except when I was able to borrow a suction pump from a friendly garage owner). As this operation was usually followed within 36 hr. by more heavy rain, it came to be left for rather long intervals, as it did not seem that the presence of the water would have any appreciable effect on temperature which changes so slowly at all times, once it has reached thermal equilibrium with its environment. It soon became apparent, however, that

after heavy rain ($\frac{1}{4}$ in. or more in a day) this thermometer tended to read about 0·2°F. higher than it should. As these effects were noted only in winter, when the rain water might be expected to be warmer than the earth and the surface to be colder than the depths, it seems that the rain carries some of its heat to a depth of at least 4 ft., even through heavy clay.

A few weeks after having arrived at this conclusion, I was interested to read in *Weather** that the same deduction had been made from temperatures observed by a completely different method.

TEMPERATURES UNDER DUTCH LIGHTS

By L. P. SMITH, B.A.

During the early months of 1949 and 1950 readings of mercury-in-steel distant-reading thermographs have been taken at Botley Experimental Station (near Southampton). The bulbs were placed at a height of 4–5 in. under Dutch lights (a cold frame) of 5-light and 2-light size, and at the same height in the open. The bulbs were screened from direct radiation and no crops were grown in the vicinity. The soil under the lights was not watered. Examination of the charts, part of one of which is reproduced in Fig. 1, shows the following results.

Rise in minimum temperature under the lights.—There is no evidence of any significant difference between the minimum temperatures in the 5-light and 2-light frames during February. As the season progresses there is an increasing tendency for the minimum temperature in the 2-light frame to be the higher. As, however, the degree of accuracy of the thermographs is of the order of ± 1°F., and as the exact siting of the themometer within the frame may have an effect of the same order, this cannot be regarded as a firm conclusion.

TABLE I—MEAN DIFFERENCE BETWEEN MINIMUM TEMPERATURES IN 5-LIGHT AND 2-LIGHT FRAMES

	February	March 1–15	March 16–31	April	May	June
Mean Difference (°F.) ...	0·0	0·6	1·1	1·0	2·0	3·9
No. of comparisons ...	26	26	27	11	6	7

TABLE II—FREQUENCY OF RISES OF DIFFERENT VALUES

	(Mean of minima under lights)−(minimum in open), °F.												Total	Mean
	<0	0, 0·5	1, 1·5	2, 2·5	3, 3·5	4, 4·5	5, 5·5	6, 6·5	7, 7·5	8, 8·5	9, 9·5	10, 10·5		
	number of occasions													°F.
Feb.	3	2	4	6	4	7	4	3	...	...	...	...	33	2·9
Mar.	2	7	1	9	7	9	5	5	3	3	3	...	54	4·0
Apr.	0	3	4	0	0	2	2	0	2	2	1	1	17	4·9

TABLE III—FREQUENCY OF MINIMUM TEMPERATURES

		>32°F.	⩽32°F.	⩽29°F.	⩽25°F.	Lowest minimum
		number of occasions				°F.
Feb.	Under lights ...	21	12	4	0	28 (twice)
	In open ...	15	18	14	6	22
Mar.	Under lights ...	48	6	2	...	26·5
	In open ...	38	16	10	...	22·5

*BALLS, L.; Soil temperatures on tap. *Weather, London*, **5**, 1950, p. 40.

The frequency of rise of temperature taking the mean of 5-light and 2-light minima is given in Table II, and the frequency of minimum temperatures in various ranges in February and March is given in Table III.

Rises during February.—The frequency is given in the first line of Table II, the range of difference being from $-2{\cdot}5°$ to $+6{\cdot}5°$F. The frequency of actual minimum temperatures is given in Table III. The figures suggest that, although the average gain in any empty frame is not large, the number of frosts and, especially, of severe frosts is decreased considerably.

Rises during March.—The frequency is given in the second line of Table II, the range of difference being from $-0{\cdot}5°$ to $+9{\cdot}5°$F. The rise in minimum temperature appears to be related to the number of hours of sunlight during the preceding day, as shown in Table IV.

TABLE IV—RELATION BETWEEN SUNSHINE DURING PREVIOUS DAY AND RISE IN MINIMUM TEMPERATURE

Sunshine during previous day (hr.) ...	0–1·9	2·0–3·9	4·0–5·9	6·0–7·9	⩾8
Mean rise in minimum temperature (°F.)	1·9	3·8	4·4	4·7	5·4

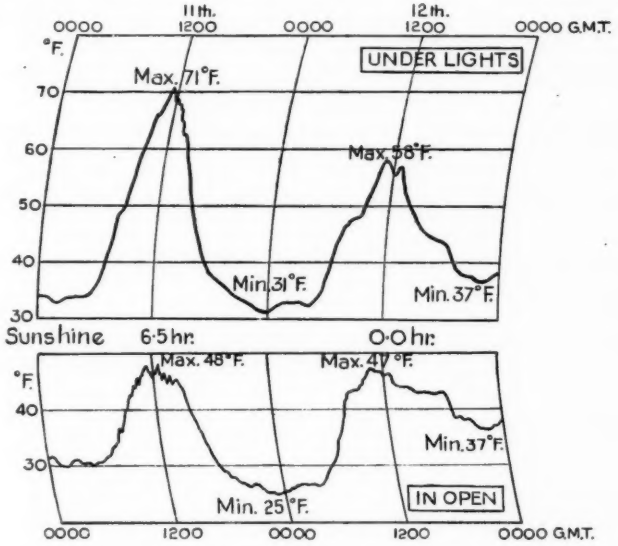


FIG. 1—THERMOGRAM OF AIR TEMPERATURES AT $4\frac{1}{2}$ IN. ABOVE BARE SOIL UNDER DUTCH LIGHTS AND IN THE OPEN

Period : March 11–12, 1949

This dependence of the rise in minimum temperature on the number of hours of sunshine in the previous day is well shown in Fig. 1. The difference between the minimum under the frame and the minimum in the open was 6°F. on the morning of March 12 following $6\frac{1}{2}$ hr. sunshine on the 11th, and zero on the following night after a day with no sunshine.

The number of frosts as shown in Table III seems to be reduced by one third in February and two thirds in March, while serious frosts are reduced by three

quarters in February and four fifths in March. It is, however, stressed that this protection may not be reached when the frames are cropped.

Rises during April.—The frequency is given in the third line of Table II, the range of difference being from 0° to 10°F. Two frosts were recorded in the open, none in the frames, where the lowest minimum was 38°F.

Again a relationship was apparent between the rise in minima and the sunshine of the previous day. With a sunshine total of 2 hr. or less the mean rise was 3·2°F., with a total of 9 hr. or more, 6·8°F.

Rise in maxima.—No very significant difference was found between the maxima in the 5-light and 2-light frames. This difference was of the order of 1°F. in February and 2–3°F. in the rest of the period, the 2-light frame being the warmer.

The simplest way to summarize the rise in maxima is to construct a table showing the average rise against the total sunshine up to 1300 during the day.

TABLE V—RELATION OF TEMPERATURE RISE TO SUNSHINE DURING THE MORNING

	Mean temperature rise for sunshine up to 1300 of			
	0–2 hr.	2–4 hr.	4–6 hr.	Over 6 hr.
	degrees Fahrenheit			
February	5·3	7·2	11·4	...
March	12·1	19·1	20·5	22·7
April	15·0	17·5	22·0	37·5
May and June	30·0	35·5	37·8	41·5

The simplest formula which can be devised to calculate the approximate rise in maximum temperature at $4\frac{1}{2}$ in. above bare ground is:—

$$D = 0{\cdot}2n + 2{\cdot}5h$$

where D is the rise in temperature, n the number of days after January 31, and h the total of sunshine hours until 1300.

Examples:—

Date	No. of days since February 1 (n)	Total sunshine before 1300 (h)	Rise in temperature (D) Calculated	Observed
	days	hr.	°F.	°F.
February 19 ...	19	0	3·8	5·0
March 12 ...	40	1·5	11·7	13·5
April 1	60	5·5	25·7	23·5

METEOROLOGICAL OFFICE DISCUSSION

Upper air climatology of the southern hemisphere

The third discussion of the 1950–51 series, on December 11, 1950, dealt with the upper air climatology of the southern hemisphere, and was opened by Mr. L. S. Clarkson who based his statement on recent papers by Loewe and Radok[1,2], Hutchings[3] and Flohn[4].

Cross-sections representing the distribution with latitude and elevation of the summer and winter means of temperature, slope of isobaric surfaces, and the derived geostrophic zonal wind component from the equator to the Antarctic along longitudes 150°E., 170°E. and approximately 10°W. are published in the papers considered. The cross-sections are based on radio-sonde data from Australia, from New Zealand and the islands in the south-west Pacific, and

from the 1938–39 voyage of the German ship *Schwabenland*. Antarctic data from Little America[5] and the various Byrd Expeditions are also incorporated.

A comparison of the cross-sections of mean thickness of the 1000–500-mb. layer along these meridians shows that, in contrast to the northern hemisphere, zonal differences are relatively slight and seasonal changes smaller. The southern-hemishere troposphere is appreciably colder in middle and high latitudes in summer, and this is possibly due to the greater cloudiness of the southern hemisphere, with its correspondingly greater reflection of solar radiation and reduced intake of heat.

The mean temperature cross-sections reveal a marked concentration of the temperature gradient, between the equator and the pole in the troposphere, into a narrow zone between approximate latitudes 20°S. and 40°S. in winter, when a region of maximum temperature in the lower stratosphere is apparent near latitude 45°S. In summer this maximum is displaced southwards to the Antarctic, resulting in a complete seasonal reversal of meridional temperature gradient in the stratosphere polewards of middle latitudes.

The 170°E. cross-section indicates that mean maximum temperature above 2 Km. in the troposphere and mean minimum temperature in the tropical stratosphere are each located a little south of the geographical equator, and also that mean temperatures in the lower stratosphere over the equator are higher in July–August than in January–February.

Defined as representing the height of minimum temperature on the mean temperature-height curves, a high-level tropical tropopause is found in low latitudes, and a low-level polar tropopause in high latitudes, with a region of overlap near 35°S. in winter and 45°S. in summer.

A comparison of the height of the tropical tropopause as found along longitude 170°E. in the southern hemisphere with that along the 80°W. meridian in the northern hemisphere[6] reveals that, whereas in the southern hemisphere the mean height is greater in summer than in winter, in the northern hemisphere the reverse is true, and in the equatorial region, where the two cross-sections overlap, they are mutually consistent in indicating a mean tropopause height 2 Km. lower in July–August than in January–February.

Meridional cross-sections showing the distribution of the geostrophic zonal wind component, as deduced from the mean meridional slopes of the isobaric surfaces, indicate in the winter season, a maximum westerly component of over 50 m./sec. at 12 Km. in latitude 25–30°S., in the region of tropopause overlap. A minimum westerly component in the upper troposphere and lower stratosphere is found in mid latitudes, and is related to the similarly located winter maximum-temperature region.

In summer the primary maximum westerly zonal wind component decreases to about 30 m./sec., and is displaced polewards to around latitude 45°S., again lying in the region of overlapping tropopauses. Along the 170°E. meridian a summer secondary jet stream of 25 m./sec. is found occupying the winter position, and a similar secondary maximum is shown in Hess's northern-hemisphere 80°W. cross-section in summer[6]. The secondary is considered to indicate the intermittent re-establishment of winter flow conditions during the summer season. A detailed comparison with Hess's northern hemisphere cross-section shows summer and winter mean jet streams of much the same intensity and height, but approximately 10° nearer the equator in the southern hemisphere.

A diagram representing together the mean temperature-height curves for the summer and winter seasons in the Antarctic and Arctic, and the annual mean curve for the equatorial region clearly shows the relatively cold Antarctic winter stratosphere, with the reversion from a winter temperature lapse rate to a summer temperature inversion, and the lower summer than winter Antarctic tropopause.

The reversal from winter westerly to summer easterly zonal winds in the stratosphere is related to the seasonal rise in the Antarctic stratospheric temperature, which, above 12 Km., is lower in winter and higher in summer than over the equator. Similarly, variations in the intensity of the tropospheric circulation between the seasons and between the hemispheres are also related respectively to the mean seasonal and inter-hemisphere temperature differences over polar regions.

The opener concluded by suggesting the possible occurrence of fairly well marked mass ascent in the Antarctic winter stratosphere, the thermodynamic effects of which would lead to the observed lifting and eventual destruction of the tropopause inversion, and to stratospheric temperatures decreasing with height in this season. The large seasonal fall of temperature in the Antarctic stratosphere would be an indirect result of such ascent[7] which would involve a return flow equatorwards at high levels[8] with mass descent towards the equatorial tropopause, where such descent would account for the observed lower tropopause and warmer stratosphere at this season. Finally, observations from the southern hemisphere are apparently inconsistent with Rossby's theory[9] that the jet stream is produced through the agency of lateral mixing processes, for, according to this theory, the greater the intensity of such departures from zonal flow the nearer the equator should the resulting jet stream be located. However, the southern hemisphere circulation is more nearly zonal than that of the northern hemisphere, and yet its mean jet stream lies nearer the equator in each season.

The Director opened the discussion which followed by welcoming the increasing amount of upper air data which is now becoming available from the southern hemisphere as a result of the extension of the use of radio-sonde apparatus. He referred to the general adoption of the expression " jet stream " in American terminology, but deprecated the use of this phrase in the British Service until its meaning has been more adequately defined.

Mr. H. H. Lamb thought that zonal differences in the circulation of the southern hemisphere are quite appreciable, and, in support, showed maps of average surface pressure for Antarctic regions in which mean troughs and ridges were very apparent, the isobars deviating widely from parallelism with the circles of latitude.

Dr. A. H. R. Goldie said that he had wondered for many years whether V. Bjerknes' idea that sunspots were the ends of a vortex tube in the sun which was mostly zonal in length but became radial at the ends had any application to the earth's atmosphere. It might be that jet streams were produced by the transference downwards of high-level vorticity in some similar manner. He then referred to observations from Heliopolis which show the tropical tropopause at a lower height in summer than in winter, and concluded by noting the great progress made in upper air meteorology in the southern hemisphere in the last ten years.

Miss N. Carruthers doubted whether temperature distribution asymmetric about the equator was characteristic of the southern hemisphere in general, but found some additional evidence partially confirming the relatively colder equatorial stratosphere in December–February. She also referred to the records of a Japanese ocean weather station which confirm the existence of either a low-level polar or a high-level tropical tropopause in these latitudes. Miss Carruthers said that work on the statistics of upper air observations shows that in the northern hemisphere no one meridian may be taken as representative, but in the other hemisphere meridional differences are much less.

Dr. R. C. Sutcliffe said that, over the United Kingdom, a jet stream can usually be found lying in the warm air over every significant front, and indeed most research shows the jet stream is positionally associated with the polar front. If the southern hemisphere westerly zonal wind maximum is similarly related to frontal air-mass discontinuities, then, while he would not be surprised at finding a front occasionally displaced well to the north, yet he would feel dubious about expecting the mean frontal position as near the equator as the mean westerly zonal wind maximum has been found in these papers discussed.

Another speaker said that experiences whilst forecasting at Capetown had suggested that cold fronts could sweep northwards over south Africa and could be traced north of the equator, where their arrival coincided with the development of associated weather phenomena at Accra and Takoradi in west Africa.

Dr. A. G. Forsdyke referred to an occasion when he had flown through a well marked and active cold front as far north as 27°S., and also spoke of cold fronts penetrating equatorwards as far as Sydney and Durban.

Mr. J. G. Galloway pointed out that the radio-sonde observations on which these papers are based were largely obtained during war time, and may become much less frequent. He suggested that a radio-sonde unit might be attached to a " round-the-world " ocean liner with the object of obtaining recordings along a circle of latitude and so investigating meridional upper air differences more directly. He asked whether several jet streams may co-exist over a series of frontal surfaces.

Mr. E. Gold pointed out that the strongest winds in the southern hemisphere do not necessarily occur in the latitude of maximum mean westerly zonal wind component, since this latitude may merely indicate the position of the most persistent westerly flow, whereas elsewhere stronger easterly and westerly winds may alternate, or meridional components may be large.

Mr. E. J. Sumner compared the circulations of the two hemispheres in relation to " blocking action ", and did not think that Loewe and Radok's results for the 150°E. meridian disproved Rossby's theory that the jet stream results from the equalization of vertical vorticity through the agency of large-scale lateral mixing.

Miss Carruthers stated that a statistical treatment of wind observations lends support to Mr. Gold's remarks, in that mean wind speed (as distinct from mean westerly component) is found to decrease towards the equator.

Mr. Clarkson, in reply, stated that a comparison between Flohn's summer meridional cross-section in approximately 10°W. and the corresponding cross-sections along the 170°E. and 150°E. meridians undoubtedly shows that

the position and intensity of the mean maximum westerly geostrophic zonal wind component is much the same in each of these longitudes, and that consequently the evidence from these papers definitely supports the contention that southern hemisphere zonal differences, though not entirely negligible, are nevertheless much less than in the northern hemisphere, where, as Miss Carruthers emphasized, no one meridian is generally representative. Differences between mean surface conditions along different longitudes are no doubt much greater than at higher levels, as Mr. Lamb's maps of mean-sea-level isobars suggest.

The evidence for an asymmetrical latitudinal distribution with respect to the geographical equator of mean maximum temperature in the troposphere and of mean minimum temperature in the stratosphere is confined to that obtained by Hutchings for the 170°E. meridian, and the asymmetry does not necessarily apply to all longitudes in the southern hemisphere.

The work of Cressman shows that the development of the jet stream in high latitudes is usually followed by a progressive displacement equatorwards, and that during this period of displacement the jet frequently divides into two streams. The double jet stream is most probably associated with the arctic and polar fronts, but the coincidence of the location of the secondary maximum in the mean westerly zonal wind component in summer with that of the winter maximum seems significant.

REFERENCES

1. LOEWE, F. and RADOK, U.; A meridional aerological cross-section in the southwest Pacific. *J. Met., Lancaster Pa.*, **7**, 1950, p. 58.
2. LOEWE, F. and RADOK, U.; Some amendments to " A meridional aerological cross section in the southwest Pacific". *J. Met., Lancaster Pa.*, **7**, 1950, p. 305.
3. HUTCHINGS, J. W.; A meridional atmospheric cross section for an oceanic region. *J. Met. Lancaster Pa.*, **7**, 1950, p. 94.
4. FLOHN, H.; Grundzüge der allgemeinen atmosphärischen Zirkulation auf der Südhalbkugel (auf Grund der aerologischen Ergebnisse der Deutschen Antarctischen Expedition " Schwabenland " 1938/39). *Arch. Met. Geophys. Bioklim., Wien, A*, **2**, 1950, p. 17.
5. COURT, A.; Tropopause disappearance during the Antarctic winter. *Bull. Amer. met. Soc., Milton Mass.*, **23**, 1942, p. 220.
6. HESS, S. L.; Some new meridional cross sections through the atmosphere. *J. Met., Lancaster Pa.*, **5**, 1948, p. 293.
7. READ, R. J.; The role of vertical motions in ozone-weather relationships. *J. Met., Lancaster Pa.*, **7**, 1950, p. 263.
8. HOFFMEISTER, C.; Die Strömungen der Atmosphäre in 120 km. Höhe. *Z. Met., Potsdam*, **1**, 1946–47, p. 33.
9. ROSSBY, C. G., and WILLETT, H. C.; The circulation of the upper troposphere and lower stratosphere. *Science, New York N.Y.* **108**, 1948, p. 643.

ROYAL AERONAUTICAL SOCIETY AND ROYAL METEOROLOGICAL SOCIETY

Clear-air turbulence

A joint discussion meeting was held at the Institute of Civil Engineers on December 14, 1950, when Dr. G. S. Hislop read his paper: " Clear-air turbulence over Europe."

Dr. Hislop gave a description and the results of the experimental flights made over west European air routes by two Mosquito aircraft of the British European Airways under contract to the Ministry of Supply. The aircraft were based

at Cranfield, Bedfordshire, and flights were made to Rome, Lisbon, Stockholm, Iceland and other places. The objects of these experimental flights were as follows:—

(i) To determine the probable frequency and extent of turbulent areas in clear air and the magnitude of the associated gust velocities.
(ii) To determine the causes and characteristics of this turbulence.
(iii) To provide a basis for the forecasting of such turbulence.

Altogether some 92,300 miles of experimental flight were made between the levels of 15,000 and 37,000 ft.

Dr. Hislop displayed several interesting statistics of the occurrence of turbulence on these flights. For example he gave the number of miles an aircraft would have to fly, on the average, before meeting gusts of various magnitudes, and compared his results with similar statistics obtained in America for lower altitudes. He also compared the mean gust spacing in clear air with that in thunderstorm clouds. It appears that small gusts are met more frequently at high than at low altitudes and that the reverse is true of the larger gusts. Large gusts are much more frequent and more closely spaced in thunderstorms than in clear air at high altitude. Though the largest equivalent gust encountered in the B.E.A. flights was 26 ft./sec. equivalent airspeed (British definition), there is reason to believe that gusts of at least 35 ft./sec. do occur over western Europe in clear air.*

Dr. Hislop then went on to consider the meteorological aspects. The lack of warning of this turbulence at high altitude makes it important to be able to forecast it but before this can be done the causes of the turbulence must be discovered and understood. Dr. Hislop thought that the main cause was the breakdown of smooth flow into eddies by large shear of wind in the vertical as envisaged by Richardson[3], though the evidence for this from the B.E.A. data was not conclusive, lack of upper air observations making deductions impossible in many cases. The horizontal gradient of temperature had been tried as a means of deducing shear in the vertical, using geostrophic and thermal wind assumptions, and the three results obtained showed that the method had promise. Dr. Hislop thought that present upper air observations, even over the British Isles where they are comparatively numerous, were too far apart in space and time for a proper analysis of this turbulence as the atmosphere is probably " patchy " and interpolation of observations therefore not justified in many cases.

Dr. Hislop then drew attention to the occurrence of high-altitude turbulence near jet streams. All jet streams encountered were not turbulent but several noteworthy turbulent incidents were associated with jet streams. Dr. Hislop also remarked on the possible associations of turbulence with the tropopause, upper air depressions, thermal instability, wind speed, the polar front and high ground; none of these appears to be a major factor in causing turbulence though they may be important on occasions. He also drew attention to an unpublished report of the United Air Lines[4] which suggests, as Bannon[5] has done, that wind shear in the horizontal is a significant factor. He concluded by advising the aviator of the best means of avoiding high-altitude turbulence and the best course to take if such turbulence has been encountered.

* Equivalent gusts up to 54 ft./sec. equivalent airspeed have been recorded in thunderstorms over England[1] and up to about 70 ft./sec. over the United States.[2]

The long discussion which followed was mainly aeronautical and not of great interest meteorologically, for only two meteorologists were given an opportunity of speaking. Prof. P. A. Sheppard welcomed the paper as being of great interest to meteorologists. He emphasized the comparatively small volume of air sampled in the observations described and hoped that other investigations would be made in the future. He thought that more sensitive instruments should be used for investigating this turbulence, for a better appreciation of its nature may well lead to a full understanding of its cause. Prof. Sheppard also stressed the possible importance of horizontal shear, suggesting that instability and hence turbulence may result if horizontal shear is anticyclonic and exceeds the value of the Coriolis parameter. Dr. Scorer suggested that fluctuations of the horizontal wind speed resulting from eddies rotating about nearly vertical axes might be the cause of clear-air turbulence but Dr. Hislop in his summing up of the discussion discounted this theory, explaining that such fluctuations could have but small effect on a fast aircraft.

REFERENCES

1. JONES, R. F.; Relation between radar echoes from cumulus and cumulonimbus clouds and the turbulence within these clouds. *Met. Res. Pap., London*, No. 484, 1949.
2. Washington, U.S. Weather Bureau. The thunderstorm—Report of the thunderstorm project. Washington D.C., 1949.
3. RICHARDSON, L. F.; The supply of energy from and to atmospheric eddies. *Proc. roy. Soc., London*, A, **97**, 1920, p. 354.
4. HARRISON, –; Some characteristics of the upper level low and jet streams. United Air Lines Circular, No. 34, 1950, (Typescript.)
5. BANNON, J. K.; Meteorological aspects of turbulence affecting aircraft at high altitudes. *Prof. Notes met. Off., London*, **7**, No. 104 (in the press).

LETTER TO THE EDITOR
Ablation in the Scottish Highlands

I read with great interest Mr. Champion's report of the results of work done by the Durham University expedition encamped on the high Cairngorms in July 1949, which I hope may be followed by further exploits of this sort. It would be interesting to know whether the data obtained suggest any association of the rate of ablation with the rainfall amounts. Of course if the period included little or no heavy rain, it might be impossible to get any indication. The variation of ablation with temperature which the expedition demonstrated was what one would expect; but the survival of the snow-beds in the Cairngorms through the dry, warm summer of 1947 goes, with other experience of these hills, to suggest that rain, especially warm rain, even in winter, may be a more effective agent for removing snow than spells of warm, dry weather. One wonders what the greatest rates of ablation per day may be in summer or winter and what weather conditions produce them.

H. H. LAMB

November 21, 1950

REVIEWS

Climate in everyday life. By C. E. P. Brooks. 8½in. × 5½in., pp. 314, *Illus.* Ernest Benn, Ltd., 1950. Price: 21*s.*, net.

Dr. Brooks has shown remarkable courage in tackling so vast a subject in such a moderately sized volume. As he says in his introduction, " to fulfil this ambitious programme completely would require a large encyclopædia ", but

he has nevertheless covered or touched on a great deal of the ground in the course of some three hundred pages. His achievement is a very useful book, and some minor criticisms, which will be suggested later, should by no means be interpreted as serious encroachments on this main conclusion.

As one of his aims, Dr. Brooks hopes to " help enquirers to ask the right questions ", and it is probably among the most important functions of such a book to further understanding between the climatologists and those, with enormously varied interests, who apply climatological data in their own fields. But it may be equally important in two other related senses in a much wider setting: first, as a means of stimulating a greater appreciation of the patient and unremitting work of climatological observers of all types and as a direct encouragement to these observers, some of whom, very often in the past, have had no very clear idea about the great value of their work; secondly, as an indication to the general reader of the virtually unlimited scope of applied climatology in the organization of modern life and the conquest of climate, and of the many possibilities which as yet have been very incompletely realized.

Even to describe the legitimate range of a book with the present title is a difficult task, and there is some evidence, in the Introduction, in the choice and arrangement of chapters, and in numerous seemingly casual but illuminating remarks, that Dr. Brooks has a wider and grander view than he has anywhere explicitly and concisely set down. One may define the end-points: at the beginning, the obvious—no-one " would export fur coats to the equator or refrigerators to Greenland " (p. 12), and no-one would deny that, to a large extent, food, clothing, shelter, in fact all the fundamental needs of man, and many, if not most, of his other needs must be rationally related to climatic conditions; at the opposite limit, the field of speculation—the extent to which climate has determined (and will continue to affect) the rise and fall of civilizations and the energy of nations (references are given by Dr. Brooks to relevant works by Ellsworth Huntington and S. F. Markham), and beyond this to the question of the eventual control of climate. Between these two extremes is an immensely wide field, with connexions reaching out to every aspect of human activity, in which climate is always and everywhere playing some part.

Not the least important feature in many climatological applications is, of course, the quantitative determination of the importance of various factors which, in a qualitative sense, are more or less obvious, or at any rate already known. It is one of the virtues of Dr. Brooks' book that with several of his chapters he provides data, formulæ, and indications of quantitative methods, which he takes some trouble to explain to the general, non-specialist reader. Another virtue, both for the general and the specialist reader, will be found in the list of more than 150 references at the end of the book (most of which are mentioned in the body of the work). In the Preface Dr. Brooks points out that the literature is immense and widely scattered—often in technical journals—and that he cannot hope to have seen more than a small part of it. But the large selection given will in itself be extremely useful to any serious reader who cares to follow up a few of the many clues it contains.

The material given in most chapters forms a very condensed account of the diverse subjects dealt with, and it would be difficult to summarize further under

any particular heading. A glance at the section and chapter headings will show, however, something of the approach and treatment, and something of the choice of topics for fuller discussion. The three sections are: " Living with climate ", " Climate as an enemy ", and " The control of climate ". The first section deals with things as they usually are, in some sort of equilibrium, with a discussion of " The economics of climate " (Chapter I), of " The siting and design of houses and factories " (Chapter II), and of the most important climates to be met with in different parts of the world (Chapters III–VII). There are, of course, frequent comments on how man has adapted his activities, in and out of doors, to the climatic conditions. The second section emphasizes the role of climate in aggressive mood, with chapters on " The deterioration of materials " (Chapter VIII), " Atmospheric pollution " (Chapter IX), and " Climatic accidents " (Chapter X). It is of outstanding interest, with regard to the first two of these chapters, that man himself has provided the aggressor with one of his most offensive weapons, and to note how much remains to be done before it can be taken away again through the complete control of man-made pollution. In the third of these chapters the more spectacular and natural forms of the aggression are discussed—typhoons, lightning, and hail, for example—and in any such condensed account, giving the worst cases, the picture formed must be very impressive. But it is certain that, at least in industrial regions, the constant pollution menace, with its effects on materials and health, is more serious than the occasional burst of climatic bad temper with its trail of damage limited to a relatively small area. The third section indicates how man has tried to counter the climatic aggression not merely by passive adaptation (as in the earliest phases of his development) but also (throughout most of his history as man) by an increasingly positive defence (Chapter XI, " Heating, air conditioning, lighting, clothing "), and now, very recently, by tentative attempts to go over to the counter-offensive (Chapter XII, " Altering the weather ").

There are two weaknesses of the book which, it may be hoped, will be corrected in a later edition. First, there are some twenty odd places where there are misprints of some importance, or loosely phrased sentences which it would be advantageous to rewrite. There is an unfortunate concentration of the bulk of these in the first seventy or so pages, which might confuse the general reader or make the specialist rather suspicious. In particular the chart given as Fig. 1 on p. 19, " Types of climate ", though on a very small scale, shows clearly enough that the islands constituting Japan are divided between " Winter frost and snow climate " and " Typhoon and hurricane climate ". On p. 20, Japan is listed under "Cyclonic-temperate climates", while in Chapter V (pp. 130–50) Japan is described under " Sub-tropical climates with summer rainfall ", with the sub-heading " Monsoon climates of Asia ". The truth may be that the climates of Japan are so diverse that some parts of the islands could be justifiably brought under any of these (and perhaps other) headings. But if this is the view which is taken, there should at least be a note to say so.

Secondly, though this may be purely a personal opinion of the reviewer, the book would be improved by the addition of a fourth section containing a single chapter " Miscellaneous ". The general scheme is good, but with a subject so vast, there are applications of importance which will always refuse to be drawn into any logical classification, and it would serve the useful purpose of showing the encyclopædic nature of the material if a small selection of

examples could be taken, almost at random, for the reader to fit into his own scheme. Some of these examples may be a little remote from " everyday life " in the strict sense, but no more so than hurricanes, or hailstones " as large as grape-fruit ", which are discussed in Chapter X. For instance, in the sphere of temperature-humidity data alone, the British Climatology Branch of the Meteorological Office received some months ago, within a very short time, inquiries concerned with the conditions affecting the treatment of premature babies, the functioning of cooling-towers, and the storage of paintings in the basement of the National Gallery. While most of us may be equally remote from the first of these and from the "old master" stage, there is again, between the two extremes, an enormous field of applications closely connected with modern life. It would be interesting to see more examples like this, with some additional emphasis perhaps on those connected with medical practice and research, as well as with the machinery and materials side.

A. BLEASDALE

John Constable's Clouds, by K. Badt. $8\frac{1}{2}$ in. $\times 5\frac{1}{2}$ in., pp. ix + 102. *Illus.* Routledge and Kegan Paul, London, 1950. Price: 12*s.* 6*d.*

This book should appeal more to artists than to meteorologists, dealing as it does with such subjects as the lives and paintings of painters of the early nineteenth century—Constable, Dahl, Blechen and others, the technical problems that confront landscape painters and poets, and the affinity between the artistic conceptions of Constable and Wordsworth.

Meteorological interest rests partly on the fact that the three painters just named were more than usually interested in clouds, and were notably successful in painting them in a realistic manner, and partly on the author's contention that the special cloud paintings done by Constable in 1821 and 1822 were inspired by Luke Howard's scientific paper " On the modifications of clouds ", which appeared in 1820, and that the excellence of those studies, and his subsequent improved pictorial handling of clouds, were largely the result of his knowledge of Howard's classification.

It would be easier to accept the author's contention if Constable's unusual interest in " sky-scapes " had not developed long before 1820, having been fostered in early life by his duties as a windmiller. Moreover, the difficulty with clouds in landscape is how to do justice to the clouds as such and at the same time subordinate them to the requirements of the composition. There is evidence in some of Constable's early compositions that at one time he was unable to overcome this difficulty, his Glebe Farm being reproduced in this book (Plate 6) in illustration. If it is hard to see how a knowledge of Howard's classification could be a major factor in overcoming the comparatively slight difficulty of portraying clouds for their own sake, it must surely be even harder to see how it can be so important in helping to solve the more difficult problems confronting the painter.

Another point worth noting is the frequency with which clouds do not conform strictly to Howard's types, which has given rise to the rather cynical saying that " the clouds we classify are not the clouds we see". Of the three illustrations of Constable's cloud studies, Plates 3–5, all admirable representations of some of the clouds we see, only one (Plate 5) includes clouds that could fairly be described as of Howard type, and that not to such an extent as to make them suitable for inclusion in a cloud atlas. Plate 3 is a delight for the

artist but a headache for the cloud classifier. Plate 4 might have been painted on one of the hot still days of 1949, when lawns were brown and cracked, and the weather forecasts hinted at thunder. Even the black and white reproduction conveys wonderfully the feeling of such a day. Such clouds, which have some of the characteristics of altocumulus castellatus, are not uncommon in very hot weather, especially around sunrise, or soon after, but seem to have escaped the attention of cloud classifiers.

E. V. NEWNHAM

HONOURS

The New Year's Honours List, 1951, announced the appointment of Dr. A. H. R. Goldie, Deputy Director (Research) of the Meteorological Office, to be a Commander, Order of the British Empire.

OBITUARY

S. G. Purches and G. W. Walklate.—It is with deep regret that we record the death of two Air Meteorological Observers, Sergeants S. G. Purches and G. W. Walklate, and the fellow members of the crew of the meteorological Halifax aircraft which crashed off Barra Head on its return from a special meteorological reconnaisance flight on December 29, 1950. Both Mr. Purches and Mr. Walklate were Meteorological Assistants prior to their call-up for National Service. On joining the Royal Air Force, they volunteered for duty in meteorological reconnaisance aircraft and completed their training not long before the accident.

Present and former colleagues in the Meteorological Office extend their deepest sympathy to the parents of Mr. Purches and Mr. Walklate in their loss.

WEATHER OF DECEMBER 1950

Mean pressure was above 1020 mb. over an area centred near the Azores and extending north-north-westwards to about latitude 50°N., and also over a considerable proportion of the northern part of the United States westward of the Great Lakes, and in the extreme north of Canada. It was below 1005 mb. off the west coast of Norway and below 1010 mb. over Italy, Sardinia and the French Riviera.

Mean pressure was above normal over most of the north-east Atlantic, east of about 50°W. and over the Greenland Sea, the excess being more than 10 mb. over a large area between Greenland and the Azores. It was 5–8 mb. below normal over central Europe and the central part of the Mediterranean.

In the British Isles the weather was exceptionally cold with frequent snow. As far as can be estimated at present, it was the coldest December in the British Isles as a whole since the severe December of 1890, and in Scotland since 1886. Locally in the south and west of England, however, December 1933 was very slightly colder.

On the 1st a secondary depression moved east across the north of Scotland, while a trough of low pressure moved quickly east over England. In the rear of these disturbances cold air of Arctic origin covered the British Isles. The cold air accompanied by wintry showers reached northern districts during the 1st, but mild weather with rain prevailed on that day in the south. In the following days small secondary disturbances moving south in the very unstable northerly air stream caused widespread snow, heavy in some northern districts, and keen frost. Snow lay to a depth of 20 in. at Dalwhinnie (1,176 ft.),

Inverness-shire, 10 in. at Houghall, County Durham, and Cockle Park, Northumberland, and rather more than 6 in. for a time as far south as Shawbury, Shropshire. On the 6th a depression, which had developed over Iceland, moved south-east to the North Sea; the arctic air was cut off, temperature began to rise and rain occurred in most places. On the 7th a deep depression west of Iceland moved north-east, and on the 8th and 9th a secondary depression approached the west of Ireland and turned north-north-east. The weather continued comparatively mild, and rain fell generally on the 9th and 10th. Subsequently the depressions east and north-east of Iceland moved away east and another burst of Arctic air flooded the country. Depressions developed to the north-west of the British Isles in the unstable northerly current and moved south-east. One depression centred south of Iceland early on the 14th moved to south-west England, thence along the English Channel and then turned north-east to the North Sea. Considerable snow fell during this period; it lay to a depth of 14½ in. at Shanklin, Isle of Wight, 12 in. at Weymouth, 11 in. at Ventnor, and 10 in. at Scarborough, Cannington and Poole on the morning of the 15th, and 15 in. at Gorleston and 14 in. at Scarborough on the 16th. Temperature remained at or below 32°F. continuously at a number of stations from the 13th to the 15th inclusive and on the 15th, temperature in the screen fell to −1°F. at Dalwhinnie, 5°F. at Glenlivet and 8°F. at Manchester (Ringway) and Prestwick. The very cold air supply was cut off on the 17th when a depression over Iceland moved a little north-east and an associated trough moved east over the British Isles; widespread snow fell in England and southern Scotland on the 18th and rain occurred in the west and north on the 19th and 20th. Snow was 8 in. deep at Whipsnade on the morning of the 19th and there were drifts up to 5 ft. deep on the 18th and 19th. Subsequently pressure became high over Scandinavia and cold south-easterly winds prevailed in the British Isles. By the 23rd a ridge of high pressure extended south over the country from an anticyclone over Greenland, and light northerly or north-easterly winds, with local slight sleet or snow, prevailed until the 26th, when an anticyclone to the north of Scotland moved to Scandinavia and winds veered to E. Thereafter this sytem moved rather quickly south-west to Scotland and then south; weather continued cold, with slight precipitation. On the 29th and 30th a depression, north-westward of Ireland, moved slowly south-east to the Irish Sea, and on the 30th and 31st a trough of low pressure moved east over England. Snow fell rather widely and was heavy locally in northern England and parts of Wales on the 30th. At 1700 on the 30th snow lay 9 in. deep at Southport, and at 0900 on the 31st it was 6½ in. deep at Lake Vyrnwy and 6 in. at Manchester and Liverpool.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	55	6	−5·6	76	−1	102
Scotland	53	−1	−5·5	60	−2	120
Northern Ireland ...	51	13	−5·8	97	0	88

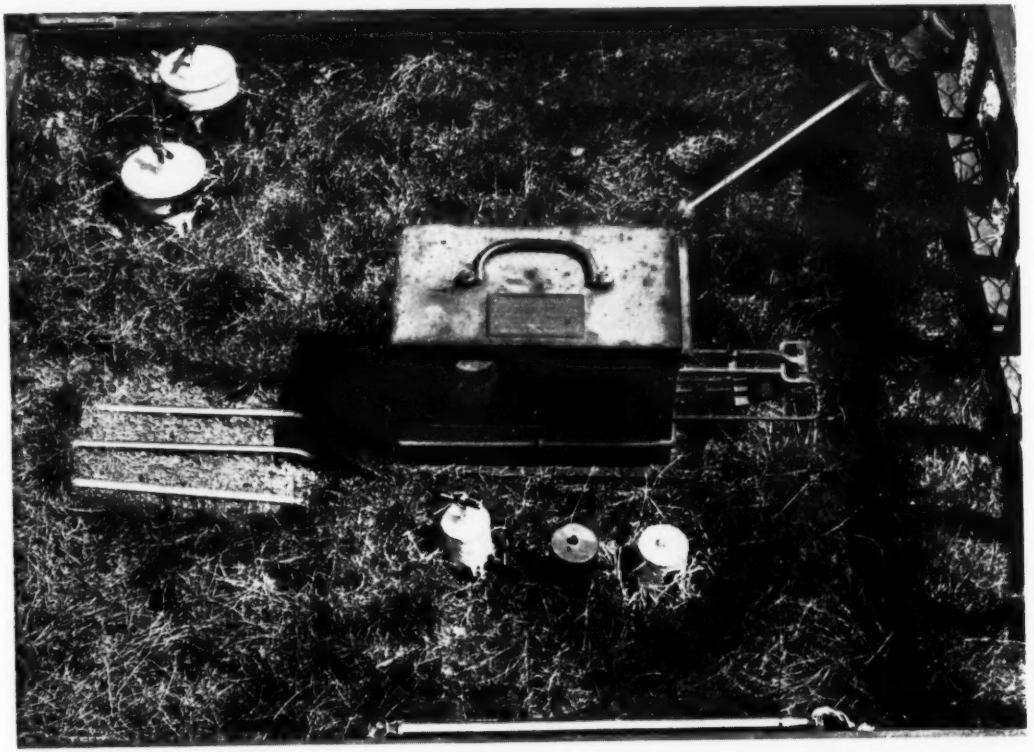
RAINFALL OF DECEMBER 1950

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·61	67	*Glam.*	Cardiff, Penylan ...	2·41	4
Kent	Folkestone, Cherry Gdn.	2·95	92	*Pemb.*	Tenby, The Priory ...	3·92	7
,,	Edenbridge, Falconhurst	2·51	76	*Card.*	Aberystwyth	3·16	7
Sussex	Compton, Compton Ho.	2·72	65	*Radnor*	Tyrmynydd	4·52	5
,,	Worthing, Beach Ho. Pk.	2·12	70	*Mont.*	Lake Vyrnwy	5·08	3
Hants.	Ventnor, Roy. Nat. Hos.	2·58	78	*Mer.*	Blaenau Festiniog ...	6·06	4
,,	Bournemouth	2·24	58	*Carn.*	Llandudno	3·04	10
,,	Sherborne St. John ...	1·60	49	*Angl.*	Llanerchymedd ...	4·38	10
Herts.	Royston, Therfield Rec.	1·21	52	*I. Man*	Douglas, Borough Cem.	3·80	7
Bucks.	Slough, Upton	1·79	71	*Wigtown*	Port William, Monreith	2·00	4
Oxford	Oxford, Radcliffe ...	1·30	53	*Dumf.*	Dumfries, Crichton R.I.	1·90	4
N'hants.	Wellingboro', Swanspool	1·43	61	,,	Eskdalemuir Obsy. ...	2·50	5
Essex	Shoeburyness	1·67	91	*Roxb.*	Kelso, Floors	1·27	3
,,	Dovercourt	1·71	80	*Peebles*	Stobo Castle	2·32	6
Suffolk	Lowestoft Sec. School ...	2·47	106	*Berwick*	Marchmont House ...	1·91	6
,,	Bury St. Ed., Westley H.	1·56	65	*E. Loth.*	North Berwick Res. ...	1·48	6
Norfolk	Sandringham Ho. Gdns.	1.86	73	*Midl'n.*	Edinburgh, Blackf'd. H.	1·56	6
Wilts.	Bishops Cannings ...	1·49	45	*Lanark*	Hamilton W. W., T'nhill	1·65	5
Dorset	Creech Grange... ...	3·59	81	*Ayr*	Colmonell, Knockdolian	2·57	4
,,	Beaminster, East St. ...	3·34	70	,,	Glen Afton, Ayr San ...	2·80	4
Devon	Teignmouth, Den Gdns.	3·59	85	*Bute*	Rothesay, Ardencraig ...	2·11	5
,,	Cullompton	3·97	90	*Argyll*	Morvern (Drimnin) ...	4·40	5
,,	Ilfracombe	4·82	100	,,	Poltalloch	1·46	2
,,	Okehampton, Uplands	5·06	72	,,	Inveraray Castle ...	3·12	5
Cornwall	Bude, School House ...	4·18	96	,,	Islay, Eallabus	3·54	6
,,	Penzance, Morrab Gdns.	5·82	102	,,	Tiree	4·11	7
,,	St. Austell	6·68	110	*Kinross*	Loch Leven Sluice ...	1·90	4
,,	Scilly, Tresco Abbey ...	4·09	87	*Fife*	Leuchars Airfield ...	1·03	2
Glos.	Cirencester	1·84	55	*Perth*	Loch Dhu	...	...
Salop	Church Stretton ...	2·51	71	,,	Crieff, Strathearn Hyd.	1·92	4
,,	Shrewsbury, Monksmore	2·01	82	,,	Pitlochry, Fincastle ...	2·05	5
Worcs.	Malvern, Free Library	1·80	65	*Angus*	Montrose, Sunnyside ...	1·42	5
Warwick	Birmingham, Edgbaston	1·67	62	*Aberd.*	Braemar	1·84	5
Leics.	Thornton Reservoir ...	1.34	50	,,	Dyce, Craibstone ...	2·38	7
Lincs.	Boston, Skirbeck ...	1·34	62	,,	Fyvie Castle	1·84	5
,,	Skegness, Marine Gdns.	1.10	50	*Moray*	Gordon Castle	3·09	11
Notts.	Mansfield, Carr Bank ...	1·61	56	*Nairn*	Nairn, Achareidh ...	1·84	9
Derby	Buxton, Terrace Slopes	4·14	73	*Inverness*	Loch Ness, Garthbeg ...	3·33	7
Ches.	Bidston Observatory ...	3·08	116	,,	Glenquoich	6·09	4
Lancs.	Manchester, Whit. Park	3·49	108	,,	Fort William, Teviot ...	3·29	5
,,	Stonyhurst College ...	3·13	65	,,	Skye, Duntuilm ...	2·88	4
,,	Squires Gate	2·96	95	*R. & C.*	Tain, Tarlogie House ...	2·00	7
Yorks.	Wakefield, Clarence Pk.	1·36	56	,,	Inverbroom, Glackour...	5·61	7
,,	Hull, Pearson Park ...	2·61	108	,,	Applecross Gardens ...	6·50	10
,,	Felixkirk, Mt. St. John	3·07	127	,,	Achnashellach	6·48	6
,,	York Museum	1·83	82	,,	Stornoway Airfield ...	6·63	11
,,	Scarborough	4·58	192	*Suth.*	Loch More, Achfary ...	8·04	8
,,	Middlesbrough... ...	2·89	149	*Caith.*	Wick Airfield	4·56	14
,,	Baldersdale, Hury Res.	1·88	51	*Shetland*	Lerwick Observatory ...	3·27	6
Norl'd.	Newcastle, Leazes Pk....	2·02	86	*Ferm.*	Crom Castle	2·98	7
,,	Bellingham, High Green	2·47	68	*Armagh*	Armagh Observatory ...	2·67	8
,,	Lilburn Tower Gdns. ...	2·86	109	*Down*	Seaforde	3·04	7
Cumb.	Geltsdale	1·57	41	*Antrim*	Aldergrove Airfield ...	3·91	11
,,	Keswick, High Hill ...	2·60	39	,,	Ballymena, Harryville...	4·21	9
,,	Ravenglass, The Grove	2·62	57	*L'derry*	Garvagh, Moneydig ...	5·28	13
Mon.	Abergavenny, Larchfield	2·13	48	,,	Londonderry, Creggan	5·17	11
Glam.	Ystalyfera, Wern House	4·90	59	*Tyrone*	Omagh, Edenfel ...	3·77	8

[*To face p. 64*

EARTH THERMOMETER SHOWING THE "COLLAR" TO PREVENT CONVECTION
(see p. 48)



ENGLOSED PATCH OF GRASS FOR EARTH THERMOMETERS AT CUDDINGTON, SURREY
Caps of tubes referred to are painted white (see p. 48).